Technology Brief 3: Microwave Ovens

Percy Spencer, while working for Raytheon in the 1940s on the design and construction of ***magnetrons*** for radar, observed that a chocolate bar that had unintentionally been exposed to microwaves had melted in his pocket. The process of cooking by microwave was patented in 1946 and by the 1970s, microwave ovens had become standard household items.

Microwave Absorption

A microwave is an ***electromagnetic wave*** whose frequency lies in the 300 MHz–300 GHz range (see Fig. 1-16.) When a material containing water is exposed to microwaves, the water molecule reacts by rotating itself so as to align its own ***electric dipole*** along the direction of the oscillating electric field of the microwave. The rapid vibration motion creates heat in the material, resulting in the conversion of microwave energy into thermal energy. The absorption coefficient of water, $\alpha(f)$, exhibits a microwave spectrum that depends on the temperature of the water and the concentration of dissolved salts and sugars present in it. If the frequency f is chosen such that $\alpha(f)$ is high, the water-containing material will absorb much of the microwave energy passing through it and convert it to heat. However, it also means that most of the energy will be absorbed by a thin surface layer of the material, with not much energy remaining to heat deeper layers. The penetration depth δ_{p} of a material, defined as $\delta_{\mathrm{p}} = 1/2\alpha$, is a measure of how deep the power carried by an EM wave can penetrate into the material. Approximately 95% of the microwave energy incident upon a material is absorbed by the surface layer of thickness $3\delta_{\mathrm{p}}$. Figure TF3-1 displays calculated spectra of δ_{p} for pure water and two materials with different water contents. The frequency most commonly used in microwave ovens is 2.54 GHz. The magnitude of δ_{p} at 2.54 GHz varies between ~ 2 cm for pure water and 8 cm for a material with a water content of only 20%. This is a practical range for cooking food in a microwave oven; at much lower frequencies, the food is not a good absorber of energy (in addition to the fact that the design of the magnetron and the oven cavity become problematic), and at much higher frequencies, the microwave energy will cook the food very unevenly (mostly the surface layer).

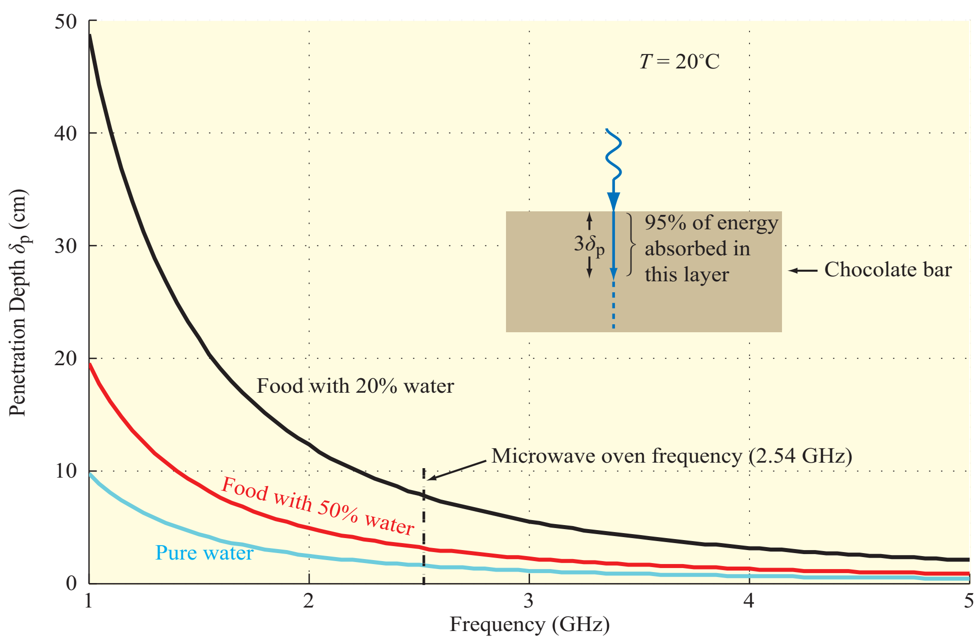
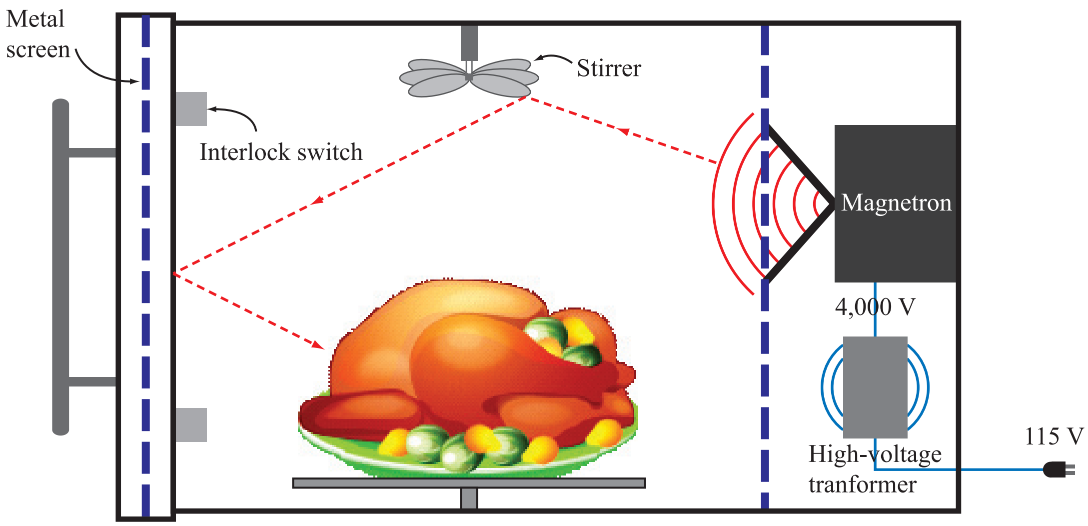


Figure TF3-1: Penetration depth as a function of frequency (1–5 GHz) for pure water and two foods with different water contents.

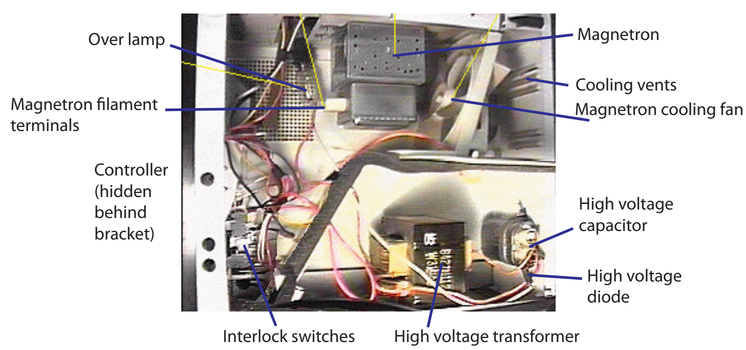
Whereas microwaves are readily absorbed by water, fats, and sugars, they can penetrate through most ceramics, glass, or plastics without loss of energy, thereby imparting little or no heat to those materials.

Oven Operation

To generate high-power microwaves (∼700 watts) the microwave oven uses a ***magnetron tube***, which requires the application of a voltage on the order of 4000 volts. The typical household voltage of 115 volts is increased to the required voltage level through a ***high-voltage transformer***. The microwave energy generated by the magnetron is transferred into a cooking chamber designed to contain the microwaves within it through the use of metal surfaces and safety Interlock switches. Microwaves are reflected by metal surfaces, so they can bounce around the interior of the chamber or be absorbed by the food, but not escape to the outside. If the oven door is made of a glass panel, a ***metal screen*** or a layer of conductive mesh is attached to it to ensure the necessary shielding; microwaves cannot pass through the metal screen if the mesh width is much smaller than the wavelength of the microwave ($\lambda \approx 12$ cm at 2.5 GHz). In the chamber, the microwave energy establishes a ***standing-wave pattern***, which leads to an uneven distribution. This is mitigated by using a rotating ***metal stirrer*** that disperses the microwave energy to different parts of the chamber.



(a) Cavity



(b) Typical microwave oven electronics bay. [Photo courtesy of John Gallawa (microtech@gallawa.com).]

Figure TF3-2: (a) Microwave oven cavity and (b) electronics bay.